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# Canister Design for Spent Fuel Disposal in a Range of Geologic Disposal Environments

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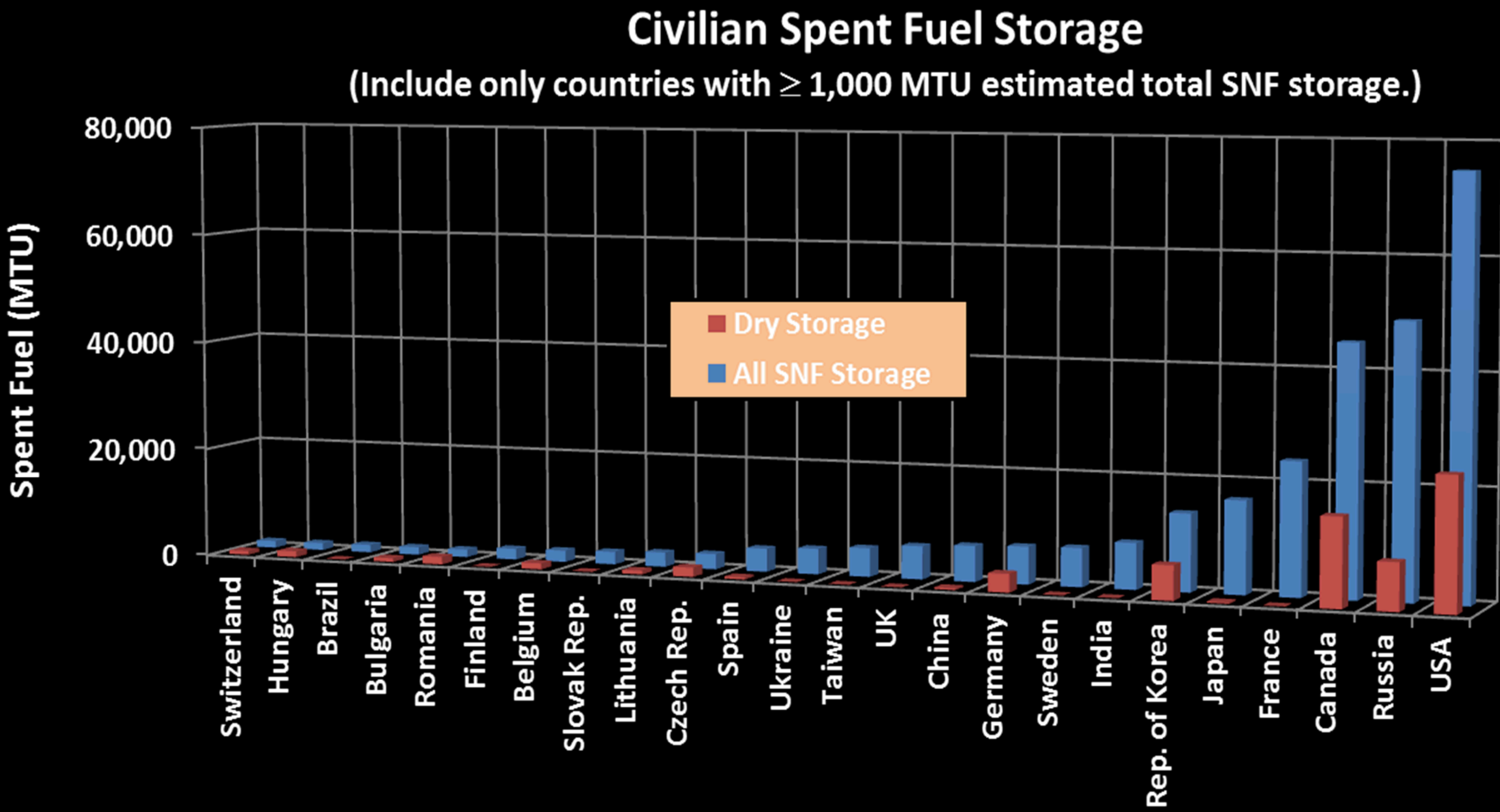
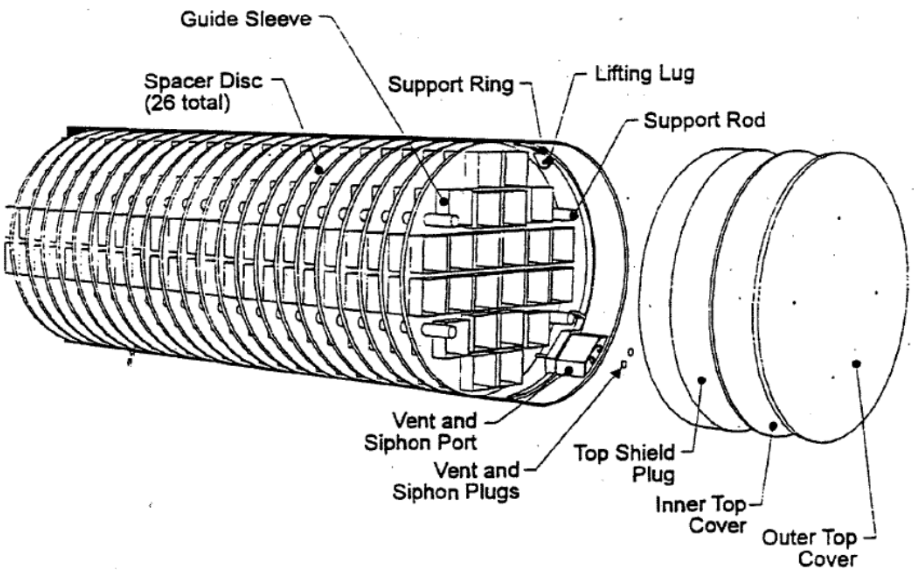

Civilian Spent Fuel Storage
(Include only countries with ≥ 1,000 MTU estimated total SNF storage.)
Spent Fuel (MTU)
80,000
60,000
40,000
20,000
0
Dry Storage
All SNF Storage
Switzerland
Hungary
Brazil
Bulgaria
Romania
Finland
Belgium
Slovak Rep.
Lithuania
Czech Rep.
Spain
Ukraine
Taiwan
UK
China
Germany
Sweden
India
Rep. of Korea
Japan
France
Canada
Russia
USA

# Some SNF Terminology

- Canister ≡ Thin-walled, typically weld-sealed, unshielded container for storing, transporting and possibly disposing of SNF, using different overpacks.
- Storage Overpack ≡ Heavily shielded, stationary, vault-like container for *canistered* SNF. Bolted closure.
- Transportation Overpack ≡ Shielded, transportable container for *canistered* SNF. Bolted closure.
- Dual-Purpose Canister (DPC) ≡ Canister that is part of a system with storage and transportation overpacks, and thereby suitable for storage and transportation.

- Storage Cask ≡ Shielded, stationary container into which "bare" SNF can be loaded directly for storage. Typically bolted closure.
- Transportation Cask ≡ Shielded container for transporting (or storing) "bare" SNF assemblies. Typically bolted closure.

# Typical DPC Canister/Cask System - NUHOMS




- NUHOMS® (TransNuclear/Areva)
- ~1/3 of existing U.S. DPC fleet
- NUHOMS®–24P, –24PHB, –24PTH, –32PT, –32PTH1, –52B, –61BT,–61BTH, and –69BTH
- Welded SS304 construction typical (fuel pool compatibility)

- Over 50% of U.S. UNF is stored in Transnuclear (TN) designed systems (part of Areva Group)
- >650 TN storage casks
- >23,000 assemblies
- 31 U.S. sites at the end of 2010


 Hardin, E.L., Geologic Disposal Concepts for HLW and Spent Nuclear Fuel

# NUHOMS DPC Canister/Cask System, cont.


- Vertical loading & sealing
- Removable trunnions
- Horizontal storage vaults: only system stored horizontally
- Ribs in vault to promote sliding

- Use TN-MP197HB transportation overpack
- Horizontal xfer to transport cask
- Horizontal transport

# Largest, Recent DPC Designs

- Example: Magnastor DPC system (NAC International)
- Recently brought to market
- Capacity 37-PWR (equiv.)
- Thermal limits: 35.5 kW storage/24 kW transport
- Fuel cool time >4 yr OoR
- Size evolution (free market): burnup credit analysis, heat transfer features, transportation needs.

Pictures and data from NAC International website 31Mar2012

# Value Proposition: Direct Disposal of SNF in DPCs

- **Sunk cost to procure/load/store DPCs** — **~$100,000 /MTU**

  **Cost to continue through >2055:** — **~$10B**
- **Future costs for all fuel, current fleet:**

  **Unload** — **>$10,000 /MTU**

  **Transport and dispose of hull** — **>$150,000 each**

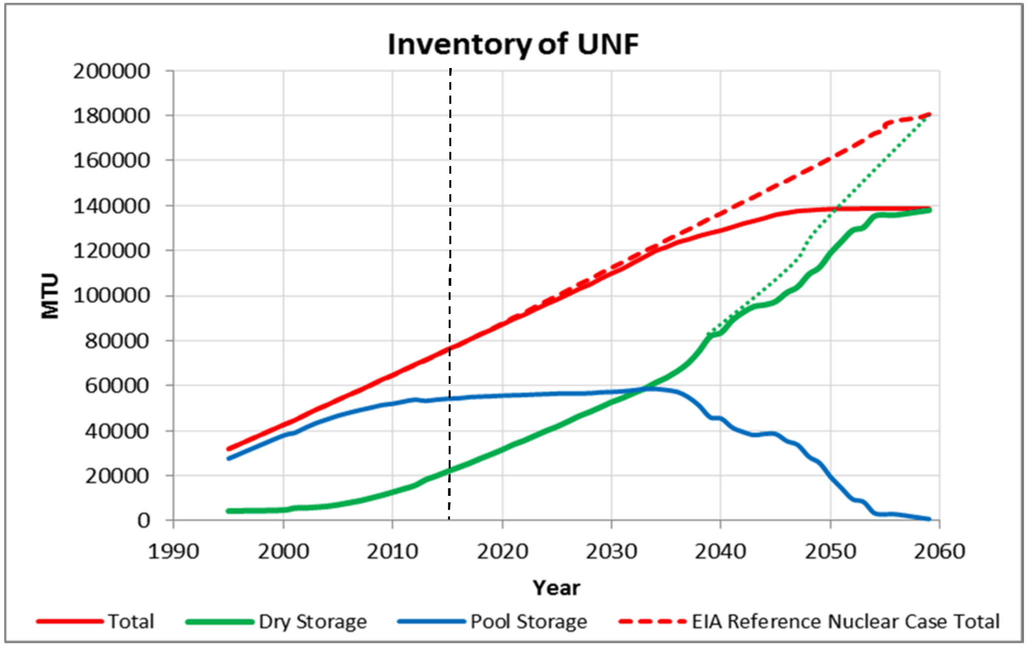
  **Re-canister for disposal** — **~$100,000 /MTU**

  **Total for 140,000 MTU** — **>$36B***

** Substantial cost savings could be achieved by:*

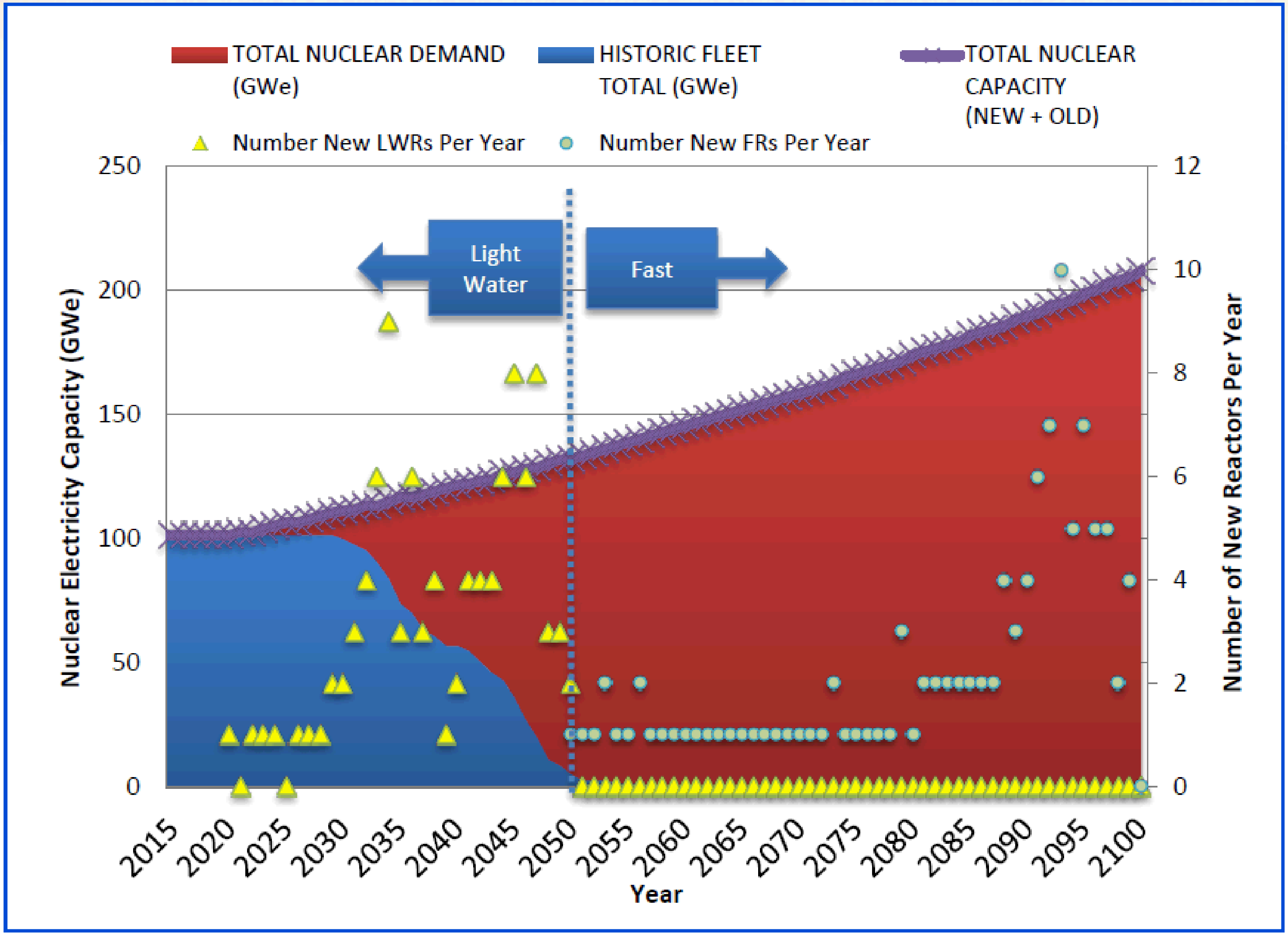
*1) Direct disposal of all DPCs; or*

*2) Direct disposal of existing DPCs, and transition to purpose-built and licensed multi-purpose canisters (storage-transport-disposal).*



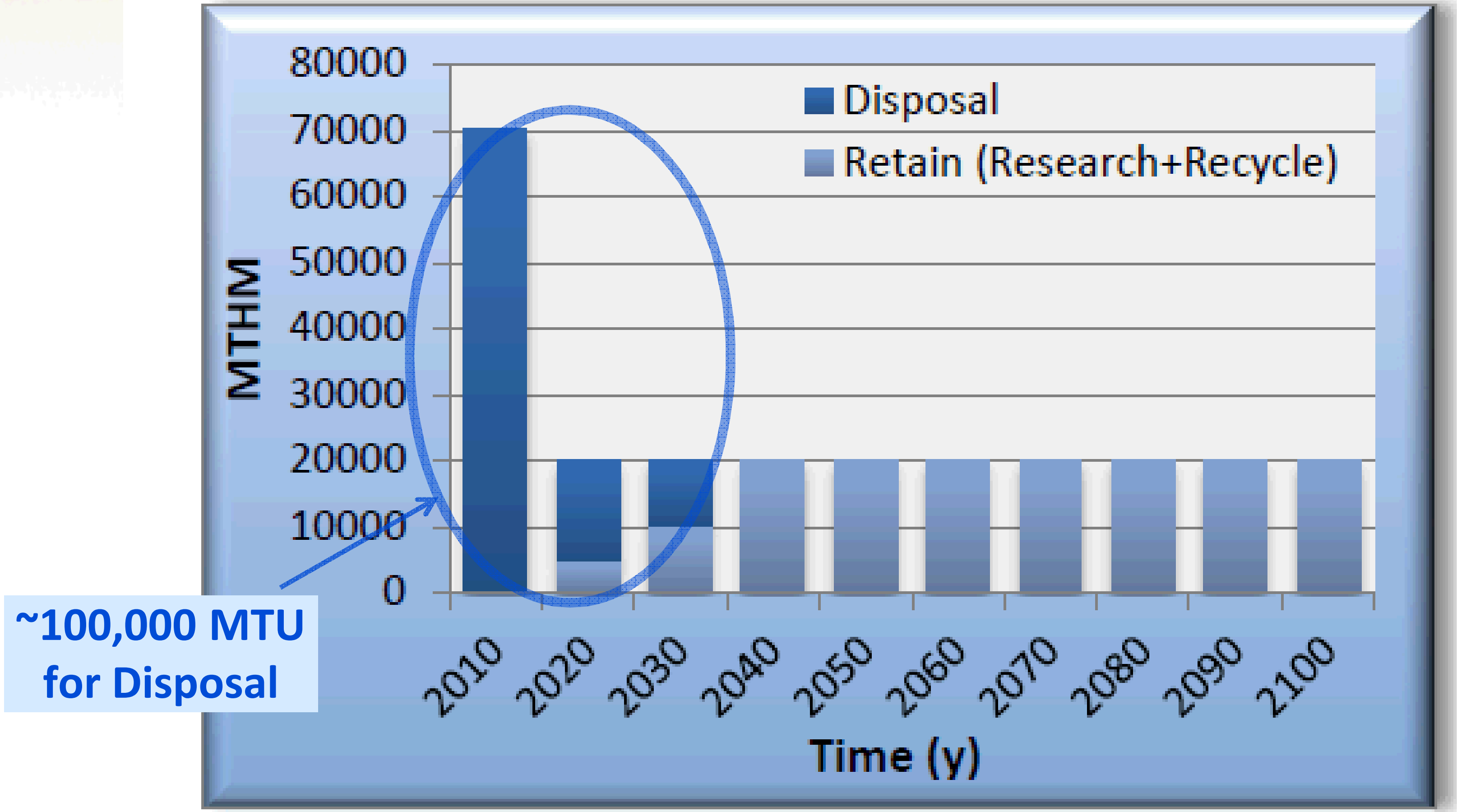
# Should We Dispose of Civilian SNF in the U.S.?

## "Optimistic" Scenario for U.S. Transition to Fully Closed Fuel Cycle




Source: Wagner et al. 2012. Categorization of Used Nuclear Fuel Inventory in Support of a Comprehensive National Nuclear Fuel Cycle Strategy. FCRD-FCT-2012-000232. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition.

# Transition to Fully Closed Fuel Cycle
## How much LWR fuel is needed to begin recycling?



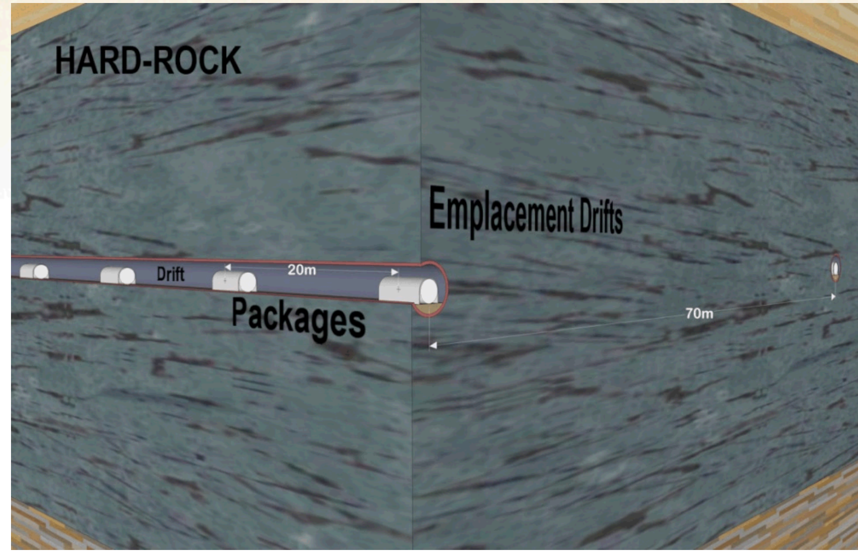

Source: Wagner et al. 2012. Categorization of Used Nuclear Fuel Inventory in Support of a Comprehensive National Nuclear Fuel Cycle Strategy. FCRD-FCT-2012-000232. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition.

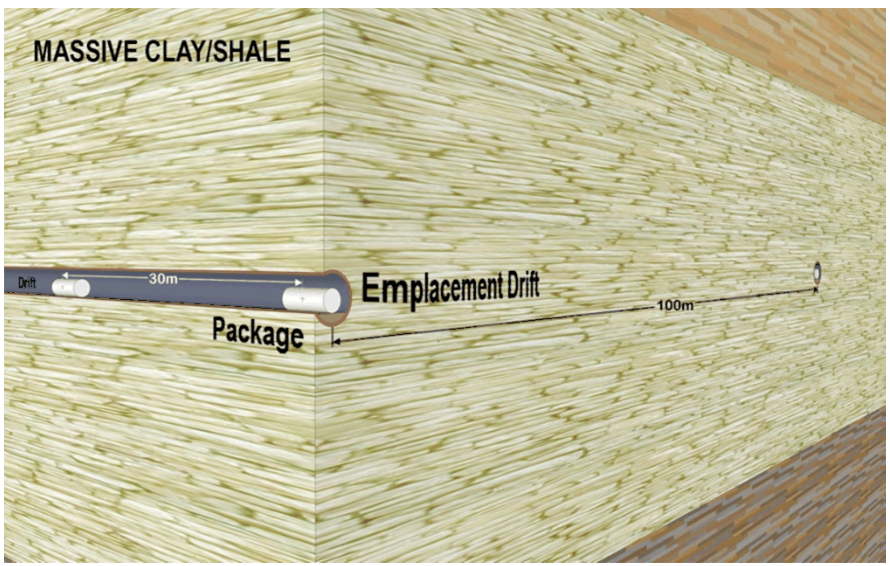
# Direct DPC Disposal Feasibility

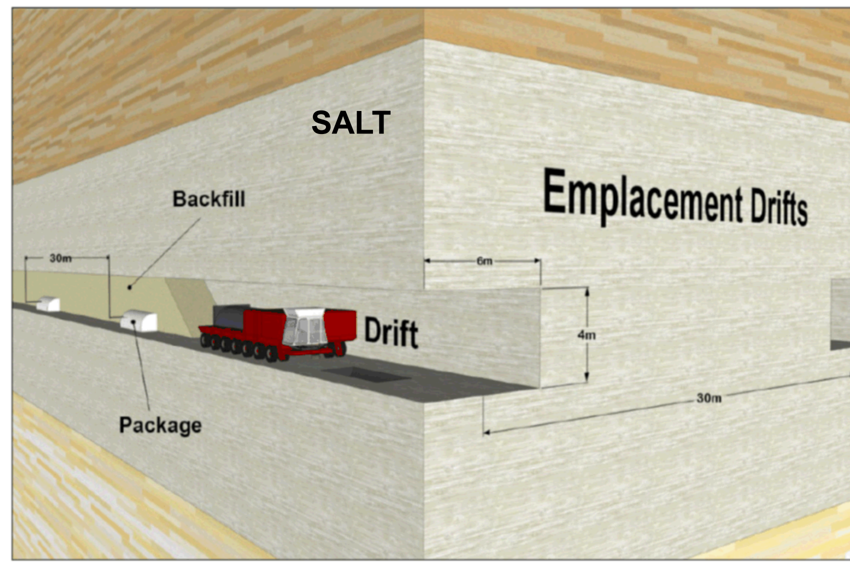
- **Safety Assessment Must Be Generic (non-site specific)**
  - SNF continues to be put into dry storage
  - Geologic repositories are not yet sited (e.g., except Sweden, Finland and France)
- **Consider Generic Disposal Media**
  - Salt
  - Hard rock unsaturated
  - Granite
  - Clay/shale
- **Technically Feasible? Consider**
  - Waste isolation postclosure safety
  - Engineering feasibility (size, weight, shielding)
  - Thermal management (size, high-burnup fuel)
  - Postclosure criticality control (flooding, absorber degradation)

# DPC Direct Disposal Concepts

- Engineering challenges are technically feasible
- Shaft or ramp transport
- In-drift emplacement
- Repository ventilation (except salt)
- Backfill at emplacement or prior to closure (except unsaturated)

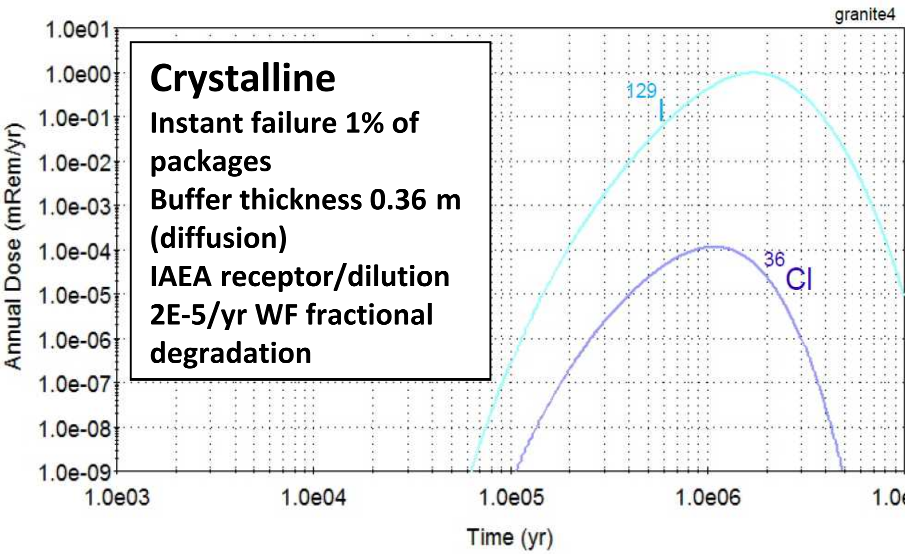


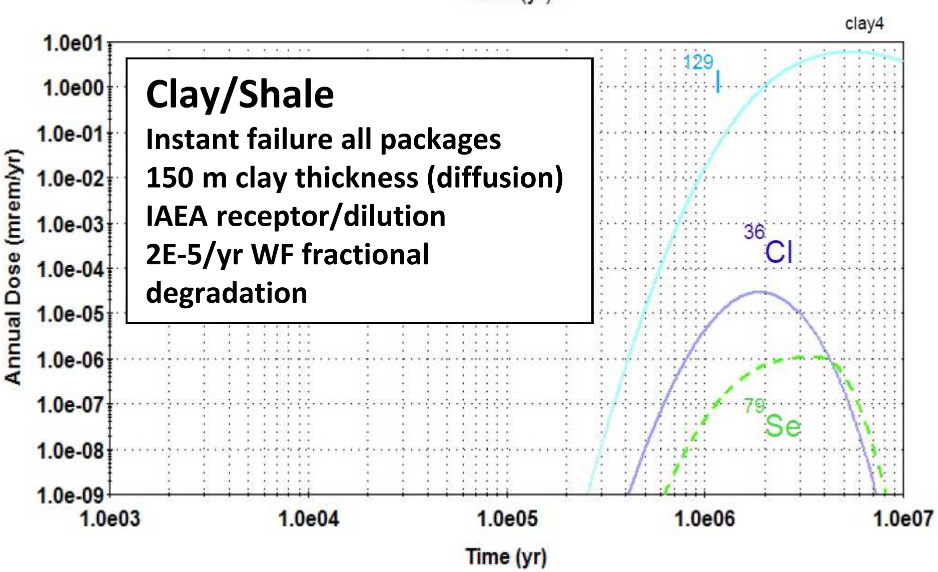



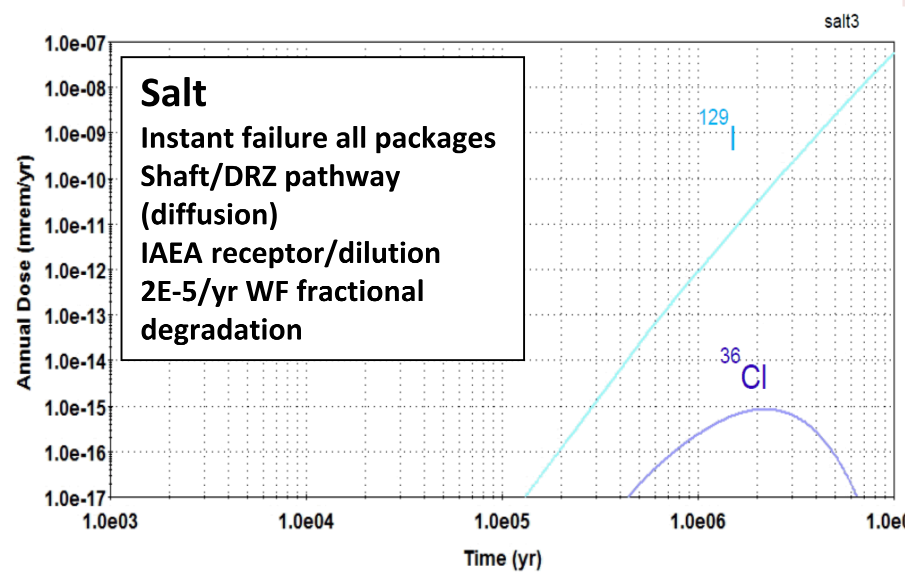

(Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 1)

# Generic Performance Assessment




- **Nominal performance, 1-D transport**
- **Diffusion-dominated barrier (natural and/or engineered)**
- **Response proportional to inventory (package size → granularity)**
- **DPC effects (nominal scenario) limited to thermal**




**(Freeze et al. 2012, FCRD-UFD-2012-000146 Rev. 1)**

# Design Options for Engineering Challenges

- **Handling/Packaging: Use Current Practices**
- **Surface-Underground Transport**
  - Spiral ramp (10% grade)
  - Linear ramp (>10% grade)
  - Shallow ramp (≤ 2.5% grade)
  - Heavy shaft hoist
- **Opening Stability Constraints**
  - Salt (a few years with minimal maintenance)
  - Crystalline (50 years or longer)
  - Hard rock (50 years or longer)
  - Sedimentary (50 years or longer)

(Hardin et al. 2012, FCRD-UFD-2012-000219 Rev. 2)

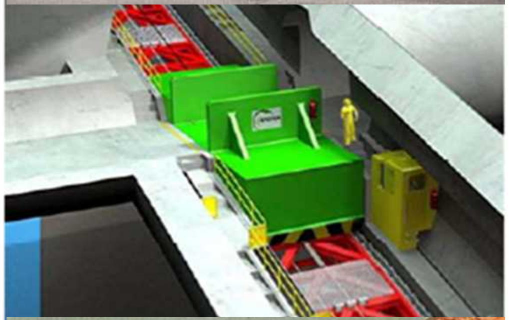
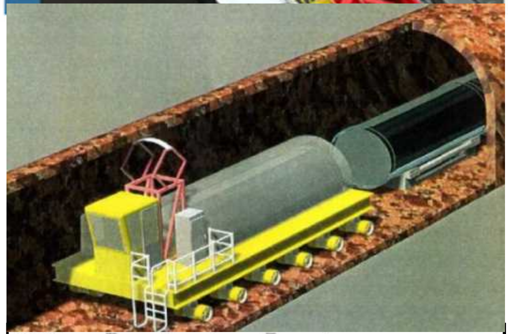
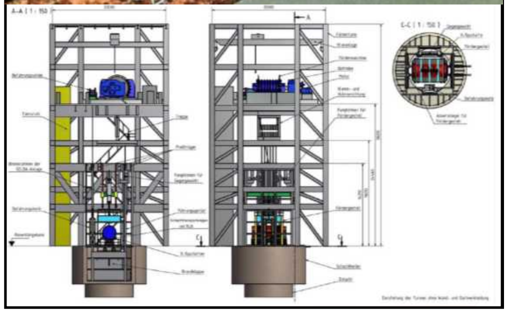
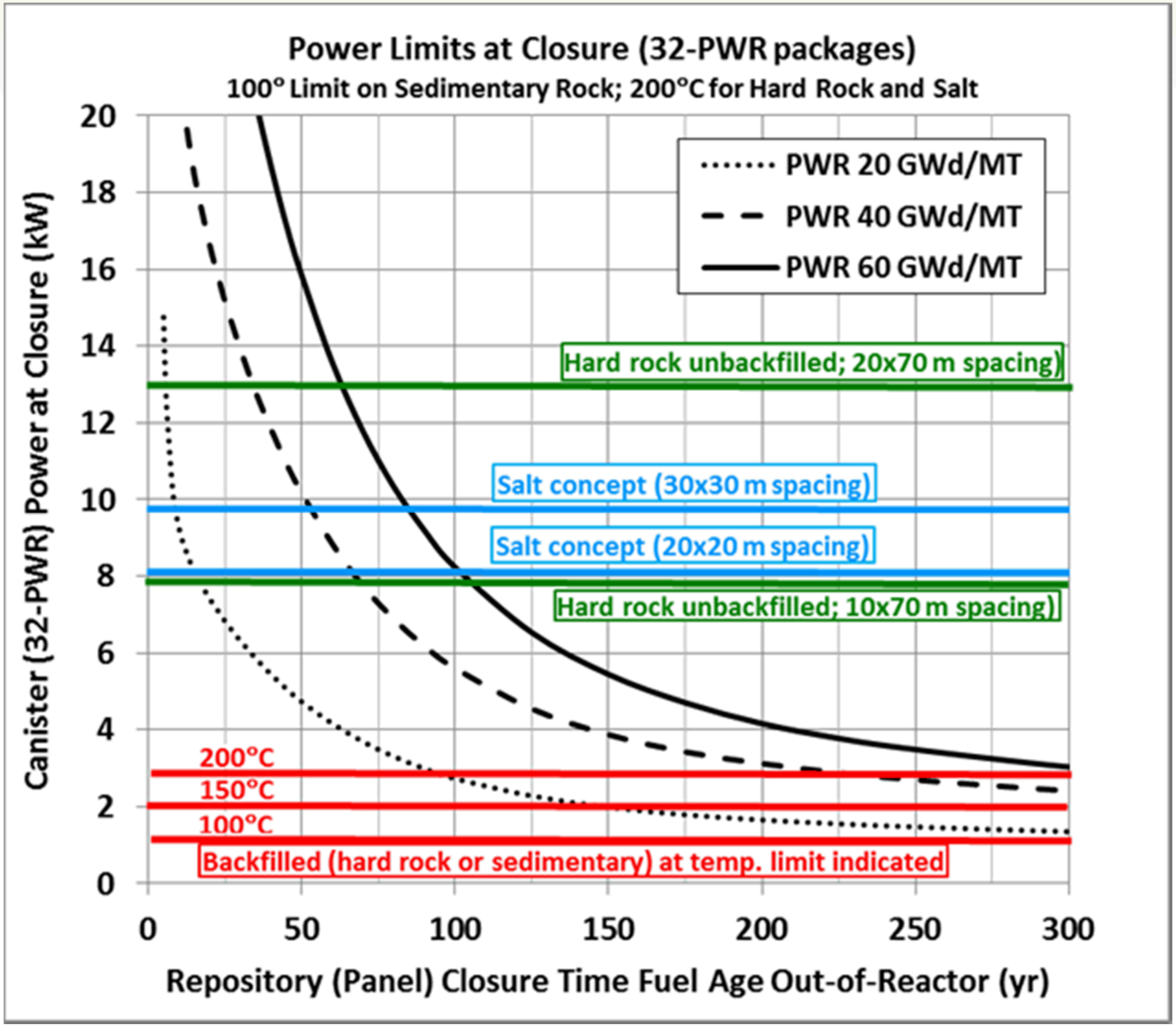





Image sources:
Fairhurst 2012
www.wheelift.com
Nieder-Westermann et al. 2013

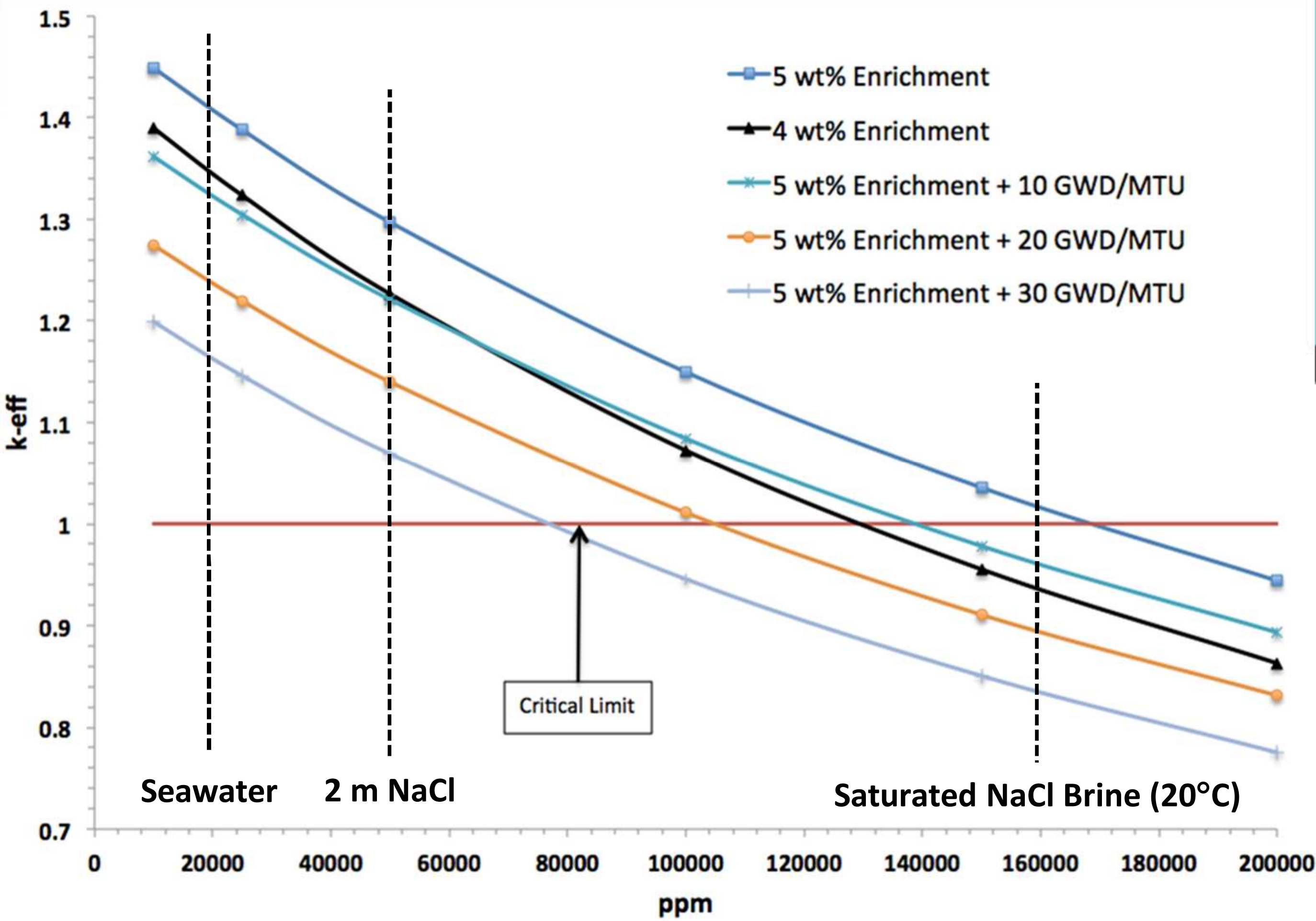
# Fuel Burnup-Aging Thermal Requirements for Disposal Concepts

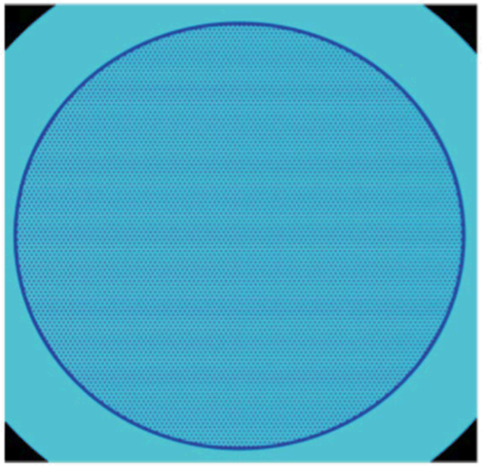



- For SNF burnup (black curves) crossing points give minimum aging time to meet peak temperature targets, for 32-PWR size packages
- Heat dissipation is best for salt and unsaturated/ unbackfilled disposal concepts
- Where backfill is used, backfill constraints dominate

(Based on Hardin et al. 2013, FCRD-UFD-2013-000170 Rev. 0)

# Criticality Analysis for High-Reactivity Stylized Case



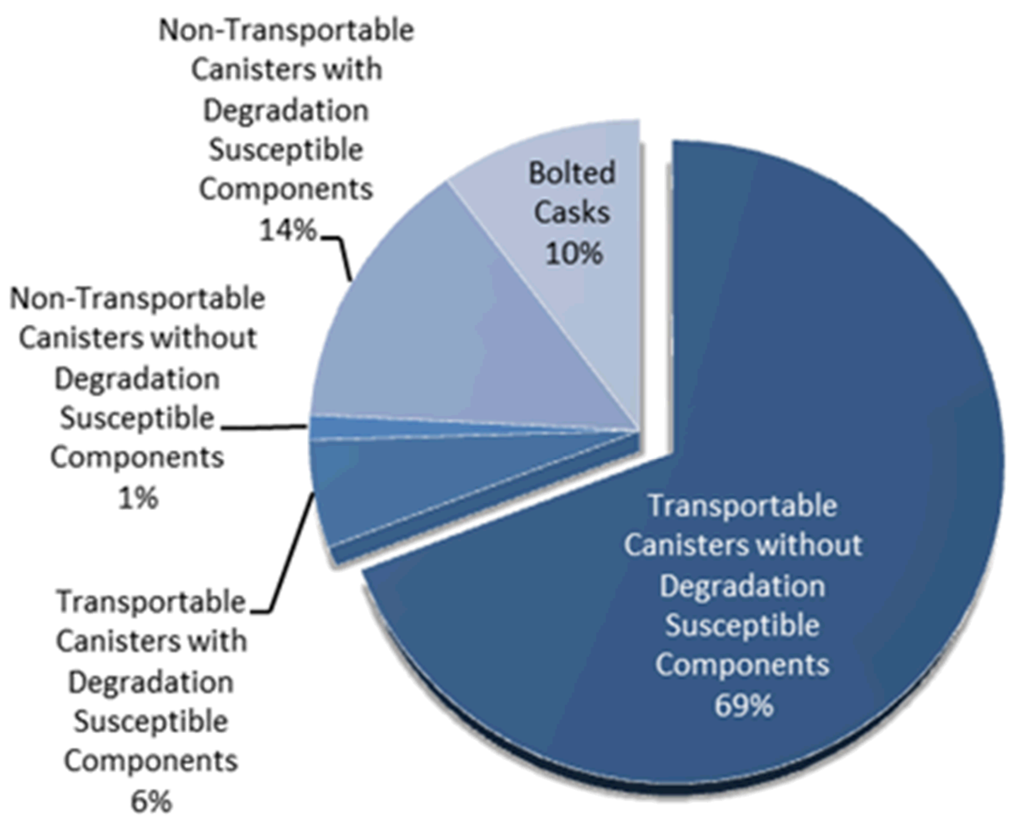



**High-reactivity case:**

- **Hexagonal array of 8617 PWR fuel rods (W17x17WL)**
- **Rods from slightly more than 32 assemblies, in a 32-PWR DPC**

**(Banerjee et al. 2014. Dual Purpose Canister Reactivity and Groundwater Absorption AnalysesFCRD-UFD-2014-000520)**

# DPC Construction Affects Potential for Postclosure Criticality and Thus, Disposability




- **Fresh-water disposal environment, flooding possible**
- **Reliance on uncredited margin (as-loaded, full burnup credit)**
- **After package breach, degradation of neutron absorbers**
- **Basket structural integrity maintains assembly fuel rod pitch**
- **Stainless steel has the longest corrosion lifetime**

# Postclosure Criticality – Summary

**Postclosure criticality position:**

- **Without flooding criticality potential is negligible**
- **Once flooded, Al-based neutron absorber materials will degrade**
- **Reactivity increase can be offset by:**
  - High-reliability overpacks (limit manufacturing defects)
  - Minimal impact of disruptive events on overpack containment
  - Available uncredited margin (for analyzed configurations)
  - Natural chloride in ground water (e.g., salt repository)
  - Fillers implemented after closure

→ ***Postclosure criticality is not a generic technical concern, at least for salt and unsaturated hard rock media***

# Technical Feasibility Study Summary

- **Technical feasibility evaluation results for:**
  - Safety of workers and the public
  - Engineering feasibility
  - Thermal management
  - Postclosure criticality control

  ***No generic or conceptual concerns***
- **Most favorable disposal concepts: salt and hard rock unsaturated/unbackfilled**
- **Transition to MPCs facilitates repository loading/closure**
  - Begin disposal with MPCs; DPCs cool 20 to 50 years later
- **Other considerations important for DPC disposability:**
  - Basket structural longevity
  - Disposal overpack reliability (better than $4.5\times10^{-5}$ /each)
  - UNF-ST&DARDS unified database (ORNL) capabilities

# Path Forward – Stakeholder Actions

**Suggested collaborative stakeholder actions (utilities, vendors, government):**

- **Develop a <u>generic disposability standard</u> and licensing basis for DPCs and MPCs (storage-transport-disposal)**
  - Mainly for postclosure criticality
  - Generic disposability case will be similar for DPCs and MPCs
- **Perform as-loaded, burnup credit analysis (e.g., loss of absorber) <u>when DPCs are loaded</u>**
- **<u>Ensure DPC lifetime in storage</u> to allow sufficient cooling for direct disposal (e.g., up to 150 yr)**
- **Collect data and analyze existing DPCs (e.g., GC-859)**

# Backup Slides

# U.S. Spent Fuel Inventory

- **CSNF Projection**
  - **Extend all operating reactors→ 60 yr**
  - Last shutdown 2055 (140,000 MTHM total)
  - Avg. burnup ~45 GWd/MT

- **Pool Storage**
  - **~60,000 MTHM capacity**
- **Dry Cask Storage**
  - **~20,000 MTHM current**
  - **+2,000 MTHM/yr**
  - **1/2 of all SNF by ~2035**







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# "Hallway" Engineering Rumors

- **"DPCs are much heavier than YM TADs."**

  *Loaded Magnastor (47 MT) vs. loaded TAD (< 49.3 MT)*

- **"DPCs are much larger than YM TADs."**

  *Magnastor canister (1.80 m D x 4.87 m L → 12.4 m$^3$) vs. TAD dimensional envelope (1.69 m D x 5.39 m L → 12.1 m$^3$)*

- **"DPC-based waste packages would be too heavy to lower down a shaft."**

  *Not necessarily, e.g., DPC package (70 MT) with shield (80 MT) + carriage < 175 MT (DBE TEC DIREGT conceptual hoist design)*

- **"DPC-based packages would be too big/hot/heavy for a salt repository."**

  *Package bearing stress is small (< 50 kPa) and even creep models calibrated to recent low-stress data produce < 0.5 m of sinking in 10$^4$ years, without interbeds. Heating/cooling displaces packages up/down due to expansion.*

Sources:


1. Greene et al. 2013. Storage and Transport Cask Data for Used Commercial Nuclear Fuel – 2013 U.S. Edition. ATI-TR-13047.
2. BSC 2008. *Basis of Design for the TAD Canister-Based Repository Design Concept*. 2008000-3DR-MGRO-00300-000-003.
3. Hardin & Kalinina 2015. *Cost Estimation Inputs for Spent Nuclear Fuel Geologic Disposal*. SAND2015-0687.